CO2/FE regulatory developments around the world

Results from vehicle simulation study

EC/ICCT Workshop on CO2 emissions from Heavy Duty Vehicles
Brussels, November 10th, 2011
Manfred Schuckert, Ralf Krukenberg
Introduction
GHG initiatives for HDV in major regions
Elements of a GHG reduction approach for HDV reflecting simulation results
Conclusion
History: big wins in fuel economy of HDV
-30% reduction in fuel consumption

- Reduction of fuel consumption is one of the most important customer purchase criteria.
- Competition driven drastic reduction of fuel consumption of HDV observable.
- Strong emission reduction measures restrict further fuel economy improvements.

* Test cycle not fully comparable to Lastauto Omnibus
Fuel economy has always been the competitive lever in the truck & bus business

Life cycle cost elements*

<table>
<thead>
<tr>
<th>Personnel</th>
<th>Vehicle price (incl. engine)</th>
<th>Fuel</th>
<th>Reliability</th>
<th>Total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>10</td>
<td>35</td>
<td>3</td>
<td>100</td>
</tr>
</tbody>
</table>

Life cycle costs influenced by vehicle

- Maintenance
- Fuel
- Reliability
- Total costs

Comparison of 4 leading Long Haul Tractors in Europe

<table>
<thead>
<tr>
<th></th>
<th>km/h</th>
<th>L/100 km</th>
<th>km/h</th>
<th>L/100 km</th>
<th>km/h</th>
<th>L/100 km</th>
<th>km/h</th>
<th>L/100 km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>79,60</td>
<td>37,25</td>
<td>78,31</td>
<td>36,97</td>
<td>80,16</td>
<td>38,90</td>
<td>81,46</td>
<td>38,22</td>
</tr>
<tr>
<td>1/100 km</td>
<td>79,02</td>
<td>37,03</td>
<td>79,16</td>
<td>35,76</td>
<td>80,57</td>
<td>37,13</td>
<td>81,05</td>
<td>38,02</td>
</tr>
<tr>
<td>mit AdBlue</td>
<td>79,53</td>
<td>37,01</td>
<td>79,37</td>
<td>36,39</td>
<td>80,39</td>
<td>36,57</td>
<td>81,24</td>
<td>37,61</td>
</tr>
</tbody>
</table>
| Source: Lastauto-Omnibus Feb. 2009, Germany

• Competition works: Only a difference of 4,5% in fuel consumption between the best and the worst on a distance of 620km!
HDV industry calls for the integrated approach:
- Comparison on the Route Stuttgart – Milano and back
- Reduced Operation Time combined with higher Payload

**Model Year 1965**
- Driving Time: 20:08 hrs
- Average Speed: 58 km/h
- Payload: 16 t

**Model Year 2009**
- Driving Time: 15:26 hrs
- Average Speed: 76 km/h
- Payload: 25 t

- Almost 25% less driving time and 64 l diesel savings on the route Stuttgart – Milano and return
HDV industry calls for the integrated approach:
- Higher payload together with less fuel consumption and CO\textsubscript{2}-emissions per ton and kilometer*.

<table>
<thead>
<tr>
<th>Fuel Consumption [l/100 km]</th>
<th>Fuel consumption [l/100 tkm]</th>
<th>CO\textsubscript{2} Emissions [g/tkm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP 1620</td>
<td>LP 1620</td>
<td>LP 1620</td>
</tr>
<tr>
<td>37,37</td>
<td>2,34</td>
<td>62</td>
</tr>
<tr>
<td>32 tons</td>
<td>32 tons</td>
<td>32 tons</td>
</tr>
<tr>
<td>- 15%</td>
<td>- 46%</td>
<td>- 46%</td>
</tr>
<tr>
<td>40 tons</td>
<td>40 tons</td>
<td>33</td>
</tr>
</tbody>
</table>

* measured on 1,159.6 km Transalp Test Drive

- Fuel consumption and CO2 emissions per tkm almost halved.
Regulatory activities on CO₂ for HDV in major regions

- GHG reduction standards/performance requirements in all key markets in place or under development apart from Europe.
- What is the most effective approach for Europe
  - Performance requirements vs. CO₂ declaration?
  - Regulatory approach vs. market oriented approach?
Customer demand vs. regulatory requirements

Customer Driven
(e.g. Situation Europe today)

Regulation Driven
(e.g. Situation Japan)

Key requirements for a CO2 declaration

- Regulation should not result in suboptimal solutions for fuel economy compared to market driven optima but regulation should maximally reinforce the strong market driven approach.
- CO2 declaration therefore should expose the specific use conditions and configurations in the heavy truck market (instead of limit values for non integrated vehicle designs)

Source: ACEA
### Overview on measurement methods of regulations

<table>
<thead>
<tr>
<th>Measurement Principle</th>
<th>Metrics</th>
<th>Simulation Input Data</th>
<th>Segmentation / Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>America</strong></td>
<td>g/ton-mile, gCO₂/BHP-HR</td>
<td>Separate engine (test bench) and vehicle standard (simulation)</td>
<td>Weight oriented (GVW) segment approach</td>
</tr>
<tr>
<td><strong>China</strong></td>
<td>g/vkm</td>
<td>Chassis dyno test for key type vehicles. Simulation used for variants.</td>
<td>• Most likely GVW based (&gt;3.5t) • Cycles: based on C-WHVC (Chinese version).</td>
</tr>
<tr>
<td><strong>Japan</strong></td>
<td>g/vkm</td>
<td>Vehicle Simulation with OEM specific measured input data</td>
<td>Weight oriented (GVW) segment approach</td>
</tr>
<tr>
<td><strong>Europe</strong></td>
<td>g/ton-mile</td>
<td>Vehicle Simulation with OEM specific measured input data</td>
<td>Mission specific vehicle segmentation, Mission Based Cycles: desired speed over distance, grade over distance, defined stops</td>
</tr>
</tbody>
</table>

- Current situation characterized by
  - regional markets, variety of products and therefore
  - major differences in methodological approaches
Elements of Japanese HD-Regulation

Method

Input Data

Max Engine torque
Idling engine speed
Max engine speed
Rated engine speed
T/M gear ratio
final gear ratio
Tire radius

Limits

<table>
<thead>
<tr>
<th>Category</th>
<th>Target value of Fuel Efficiency km/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Pay Load ≤ 1.5t</td>
</tr>
<tr>
<td>T2</td>
<td>1.5&lt; Pay Load ≤ 2t</td>
</tr>
<tr>
<td>T3</td>
<td>2&lt; Pay Load ≤ 3t</td>
</tr>
<tr>
<td>T4</td>
<td>3&lt; Pay Load</td>
</tr>
<tr>
<td>T5</td>
<td>3.5&lt; GVW ≤ 7.5</td>
</tr>
<tr>
<td>T6</td>
<td>7.5&lt; GVW ≤ 8t</td>
</tr>
<tr>
<td>T7</td>
<td>8&lt; GVW ≤ 10t</td>
</tr>
<tr>
<td>T8</td>
<td>10&lt; GVW ≤ 12t</td>
</tr>
<tr>
<td>T9</td>
<td>12&lt; GVW ≤ 14t</td>
</tr>
<tr>
<td>T10</td>
<td>14&lt; GVW ≤ 16t</td>
</tr>
<tr>
<td>T11</td>
<td>16&lt; GVW ≤ 20t</td>
</tr>
<tr>
<td>Tractor</td>
<td>20&lt; GVW</td>
</tr>
<tr>
<td>TT1</td>
<td>GVW ≤ 20t</td>
</tr>
<tr>
<td>TT2</td>
<td>20&lt; GVW</td>
</tr>
</tbody>
</table>
Vehicle classification and specifications (T11):

<table>
<thead>
<tr>
<th>Fuel consumption classification No.</th>
<th>Classification</th>
<th>Standard vehicle specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of gross vehicle weight (t)</td>
<td>Vehicle weight (kg)</td>
<td>Maximum loading capacity (kg)</td>
</tr>
<tr>
<td>T11</td>
<td>20 &lt;</td>
<td>8,765</td>
</tr>
</tbody>
</table>

- Official vehicle classification number T11 (70 % City, 30 % Highway)
- Standard vehicle configuration (25 t, 6x2)
- Official simulation tool: (F)ExecutionProgram.exe (TRIAS 5-8-2007)
- Driving resistances: For air-drag and rolling resistance, fixed values are used in simulation tool
- FC in idling mode is entered separately (not derived from FC map)

Notes:
- boundary conditions for FC map measurements are not exactly as defined in FES rules (consideration of auxiliaries);
- no optimization of fuel map data for FES → Resulting chances and risks are about neutral in total

• An efficient Euro VI engine and drivetrain would meet the FES target 2015 for T11 class. (high sales volume, 6x2, 25 t, 4.04 km/l)
Elements of Chinese HD-regulation

Method: Standard Framework

- 3 categories:
  - FC of Rigid Truck (NOT incl. Tipper)
  - FC of Semi-Trailer Truck Tractor
  - FC of Bus (NOT incl. City-Bus)

- Metric: L/100km

Fuel Consumption Limits

Excerpt: Tentative Proposal of FC Limits of Semi-Trailer Truck Tractor

<table>
<thead>
<tr>
<th>GCW kg</th>
<th>L/100km</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCW ≤ 18000</td>
<td>--</td>
</tr>
<tr>
<td>18000 &lt; GCW ≤ 27000</td>
<td>--</td>
</tr>
<tr>
<td>27000 &lt; GCW ≤ 35000</td>
<td>45.0</td>
</tr>
<tr>
<td>35000 &lt; GCW ≤ 40000</td>
<td>47.0</td>
</tr>
<tr>
<td>40000 &lt; GCW ≤ 43000</td>
<td>49.0</td>
</tr>
<tr>
<td>43000 &lt; GCW ≤ 46000</td>
<td>51.5</td>
</tr>
<tr>
<td>46000 &lt; GCW ≤ 49000</td>
<td>53.9</td>
</tr>
<tr>
<td>49000 &lt; GCW</td>
<td>--</td>
</tr>
</tbody>
</table>

Specifics Chinese WHVC

Gear Shifts of AMT
China - comparison Euro V / Euro VI vehicle (CATARC FC tool)

- Engine power 315 kW Euro VI and 320 kW Euro V
- Torque 2100 Nm
- Mass: 40.000 kg
- Coast-down curve generated artificially
- Same rolling resistance
- Aerodynamic improvements for Euro VI vehicle
- Same gearbox data
- Standard final gear ratio for each vehicle

Notes:
- Just simulated values, no chassis dynamometer tests
- CATARC FC tool version 1.0.0.20110225

- Both Euro V and Euro VI vehicles would meet the proposed Chinese FC limit.
Elements of CO$_2$ classification class 8 sleeper cab

**Aerodynamics** CdA

- **BIN I** (CdA $\geq 7.6$): classic tractor with features increase drag
- **BIN II** (CdA: 6.7-7.5): conventional tractor general aero shape, avoids classic features
- **BIN III**: (CdA: 5.8-6.6): EPA SmartWay, adds components to reduce drag
- **BIN IV**: (CdA: 5.2-5.7): additional aerodynamic refinements available today
- **BIN V**: (CdA: $\leq 5.1$): additional aerodynamic refinements expected available in future

**Tires**

- **Baseline**: Crr: Steer = 7.8; Drive = 8.2
- **BIN I**: Crr: Steer $\leq 6.6$; Drive $\leq 7.0$: SmartWay low resistance tires
- **BIN II**: Crr: Steer = 5.7; Drive = 6.0

**Weight Reduction**
**Elements of CO\(_2\) classification Class 8 Sleeper Cab**

### Aerodynamics \(C_{dA}\)

<table>
<thead>
<tr>
<th>BIN I</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIN II</td>
<td>Standard</td>
</tr>
<tr>
<td>BIN III</td>
<td>US Truck today</td>
</tr>
<tr>
<td>BIN IV</td>
<td>Latest EU Truck</td>
</tr>
<tr>
<td>BIN V</td>
<td>Latest EU Truck</td>
</tr>
</tbody>
</table>

**Aerodynamics of latest European truck outperforms future US trucks (trailer gap)**

### Drive & Steer Tires \((C_{rr})\)

- **Baseline**
- **Standard**
- **US Truck today**
- **Latest EU Truck**

**Highest contribution to rolling resistance:**

- (Drive Tire: 42.5%, Steer Tire 12.5%)

### Idle Reduction

- Extended Idle
- Automatic engine shutdown

**Credit of 5g CO\(_2\)/ton-mile through automatic engine shutdown**

### Weight Reduction

- **Baseline**
- **Standard**
- **Latest EU Truck**

**EU comparable to US standard**
USA – fuel map comparison

- Euro VI engine compared to NAFTA-engine fulfilling the EPA2014 CO2 limit

**US-engine CO2-limits**

<table>
<thead>
<tr>
<th>CO2G/BHP-HR</th>
<th>EPA 2013-relaxed</th>
<th>EPA 2014</th>
<th>EPA 2016/17</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fuel map comparison as indication of general efficiency levels in vehicle**

**EPA 10 Fuel Map**

Analysis shows that EPA 10 map is better in some areas, while Euro VI is better in some other areas of the fuel map. All in all the efficiency ratios are very similar.

**Euro VI Fuel Map**

Remark:
Test cycles, tailpipe NOx and vehicle operational profiles different in Europe and US!!

- Euro VI engine with comparable or even better fuel efficiency in nearly all operating points
Vehicle simulation based on the US GEM 2.0 model
- Class 8 High Roof Sleeper Cab

Facts
• For US truck today typical specifications of fleet customers are selected.
• For Europe specification of latest EU truck technology is selected.
• All trucks specification have been modeled employing official GEM model provided by EPA, using standard engine 2014.
• Based on the GEM Model and its limitations performance of latest European trucks significantly better – in reality the difference is smaller.

*) not statistically representative

• US market: most advanced trucks meeting 2014 standards.

• GEM input data for regulation relevant items, have been selected as illustrated previous slide.

• Speed limit reduction for EU truck have been considered: 55mph instead of 65 mph

• Elements of a GHG reduction approach for HDV reflecting simulation results
# Evaluation of Feasibility of technologies proposed in LOT-1

## Long Haul – Cost Effective Scenario

<table>
<thead>
<tr>
<th>Technology</th>
<th>Evaluation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Vehicle</td>
<td>![ ]</td>
<td>Long Haul not applicable</td>
</tr>
<tr>
<td>Alternative Fuelled Bodies</td>
<td>![ yellow ]</td>
<td>e.g. solar</td>
</tr>
<tr>
<td>Full Hybrid</td>
<td>![ yellow ]</td>
<td>Not cost effective</td>
</tr>
<tr>
<td>Stop/Start System</td>
<td>![ red ]</td>
<td>No fuel reduction impact in Long haul</td>
</tr>
<tr>
<td>Dual Fuel (CNG/Diesel)</td>
<td>![ yellow ]</td>
<td>CO2 reduction vs. energy efficiency</td>
</tr>
<tr>
<td>Pneumatic Booster</td>
<td>![ red ]</td>
<td>Not cost-effective according to Daimler evaluation</td>
</tr>
<tr>
<td>Controllable Air Compressor</td>
<td>![ yellow ]</td>
<td></td>
</tr>
<tr>
<td>Automated Manual Transmission</td>
<td>![ green ]</td>
<td></td>
</tr>
<tr>
<td>Aerodynamic Trailers/Bodies</td>
<td>![ yellow ]</td>
<td>Known to have high reduction potential</td>
</tr>
<tr>
<td>Aerodynamic Fairings (Tractor)</td>
<td>![ yellow ]</td>
<td></td>
</tr>
<tr>
<td>Spray Reduction Mud Flaps</td>
<td>![ green ]</td>
<td></td>
</tr>
<tr>
<td>Predictive Cruise Control</td>
<td>![ yellow ]</td>
<td>Early field tests</td>
</tr>
<tr>
<td>Automat. Tire Pressure Monitoring</td>
<td>![ green ]</td>
<td>In series</td>
</tr>
<tr>
<td>Low Rolling Resistance Tires</td>
<td>![ yellow ]</td>
<td>Already available in EU; further development activities of tire manufacturer</td>
</tr>
<tr>
<td>Single Wide Tires</td>
<td>![ green ]</td>
<td>Already available in EU</td>
</tr>
</tbody>
</table>

### EU Trucks

**Latest Technology**

- Solar panels
  - Not cost-effective according to Daimler evaluation
- Electric Vehicle
  - Long Haul not applicable
- Aerodynamic Trailers/Bodies
  - Known to have high reduction potential
  - Early field tests
- Automated Manual Transmission
  - In series
- Low Rolling Resistance Tires
  - Already available in EU; further development activities of tire manufacturer
- Single Wide Tires
  - Already available in EU
Elements of a GHG reduction approach for HDV reflecting simulation results

**Integrated approach**

- Tight resources require the consideration of entire vehicle including trailer for identifying most cost effective GHG reduction measures.
- Soft measures such as driver training can result in 5-15% fuel consumption reduction.
- Biofuel has high potential to reduce GHG emission over the entire vehicle fleet.

*Will also require changes of existing vehicle size and weight legislation*
Recommended Principles for a CO2 declaration approach

1. CO2/FE values have to be “realistic” for all to be declared vehicle variants and CO2 reduction in real world can be determined accurately
   ⇒ full vehicle approach needed including engine fuel consumption in vehicle
   ⇒ avoid split in engineering activities for declaration versus customer use
   ⇒ “realistic” means an representative value for the specific vehicle applications, despite the fact that the spread of FE at the customer is often huge
   ⇒ Assist customers in purchase decisions

2. As much as possible CO2 reduction measures should be covered, but declaration procedure need to be repeatable, robust and practicable
   ⇒ nearly all reduction potentials should occur in test/simulation procedures

3. Effort/resources for CO2- declaration reasonable for OEM’s
   ⇒ it will be more effort, but test burden should be reasonable/acceptable

• Only a full vehicle approach is able to fulfill declaration principles
# Key requirements for harmonization of test procedures vs. current status

## Key Requirements

<table>
<thead>
<tr>
<th>Key Requirements</th>
<th>USA</th>
<th>China</th>
<th>Japan</th>
<th>ACEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard for vehicle incl. engine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulation based</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measured OEM-specific engine data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measured OEM-specific vehicle data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metrics: gCO₂/tkm (ton-mile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mission Specific Vehicle Simulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market Specific Cycles incl. slope</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Chances

+ Structure and Key Components similar.
+ Phase 2 of US regulation offers opportunities to improve US standard
+ World wide initiatives justifies UN-ECE work on measuring methods/test procedures

## Risks

- Fulfillment of requirements with regional variability.
- Industry: High costs due to variety of measurement methods/test procedures.
- Customer: real world fuel consumption may not match values derived from regulation.
- Society: Inefficient use of tight resources resulting in lower real world reductions.

• Adjusting existing measurement principles essential to achieve harmonization on reasonable level.
World harmonization essentially required but regional approaches with rising variation in crucial details

*International harmonization of cycles, methods and simulation tool*

**Cycle Definition**
- Slope
- Load

**Measuring Methods / Test Procedures**
- UN-ECE:
  - Aerodynamic
  - Tires
  - Fuel Maps

**Simulation Tool**
- Simulation tool (provided by legislative bodies)

**Application of internationally harmonized standards as basis for specifically required characteristics**

**Cycles, depending on use-cases (missions)**
- Regional
- National

**Segmentation:**
- with regional/national differences

- World-wide standards for measurement of HDV fuel consumption need to be developed.
- Regional aspects (world-wide simulation/regional test cycles/vehicles/...) need to be taken into account.
Conclusion

European manufacturers & customers have given fuel efficiency high attention, all "low hanging fruits" are already harvested.

The ACEA approach of a certified declaration of fuel efficiency offers customer guidance in terms of real life results, further encouraging competition.

The integrated approach offers additional and cost effective potentials for the improvement of fuel efficiency and CO2 performance.

Thank you for your attention